Ferrocement as a Material

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Individual project for the City of Guilds of London Institute

Diploma in Advanced Concrete Technology, 1976

JENS KRISTIAN JEHRBO JENSEN

FERROCEMENT AS A MATERIAL. A literature study

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FERROCEMENT

as a material

A literature study of

Jens Kr. Jehrbo Jensen

Individual project for the City and Guilds of London Institute
Diploma in Advanced Concrete Technology, 1976

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PREFACE

This report is my individual project for the City and Guilds of London Institute Diploma in Advanced Concrete Technology, 1976.

The subject is FERROCEMENT, its composition, structure and properties and the report is the result of a literature study. To secure the literature, I have been in connection with libraries from other countries than Denmark. Some experiments have been made in the laboratories in Wexham Springs and Fulmer Granges. I extend my sincere thanks to Mr. Barton and other members of the staff for their assistance with the practice. I also wish to convey my warm gratitude to my supervisor, Mr. Alistair Gardner. The report is written by Miss Tove Jensen and the drawings are made by Mrs. Ingrid Christensen, to whom I send my sincere thanks for perfect work.

Jens Kr. Jehrbo Jensen

SUMMARY

FERROCEMENT is not a new material. In 1850 Jean Louis Lambot took out a patent on FERCIMENT, and in 1930's Pier Luigi Nervi created FERROCEMENT.

In this report the structure (meshes, rods and mortar) and composition (diameter and widths of meshes and rods, water/cement ratio, aggregate/cement ratio) are described. The mechanical properties (tension, compression, bending, impact, fatigue and dynamic behaviour) are detailed treated. The problems about permeability, freezing/thawing and corrosion are mentioned. Some new experiments are described in connection with the practical manufacturing of FERROCEMENT. Fields of applications are commented.

INTRODUCTION

FERROCEMENT is a building material, where the components are cement, fine aggregate and a reinforcement, consisting of one or more layers of woven or welded, square or hexagonal meshes uniformly distributed over the whole cross section. Mesh-reinforced concrete was introduced for the first time by Jean Louis Lambot, who in 1850 took out a patent on FERCIMENT, and he built boats, which are still with us today.

It was in the 1930's the Italian engineer and architect Pier Luigi Nervi created, what we today call FERROCEMENT. He built several boats and roofs for halls, because it was now possible to manufacture constructions of small thickness gauge, and they could be formed into shapes wanted. In the literature this story has been told repeatedly (1, 3, 4).

The basic idea behind this material is the fact, that concrete can undergo large strains in the neighbourhood of the reinforcement, and the magnitude of the strains depends on the distribution and the subdivision of the reinforcement throughout the mass of the concrete.

The advantages of using mesh-reinforced mortar instead of normal reinforced concrete is, that you get better mechanical properties and better durability. You have a material, which - within certain loading limits - behaves as a homogenous elastic material, and these limits are wider than for normal concrete.

In the following the structure, composition and several properties of FERROCEMENT will be described, together with the problems concerning workmanship. Some examples of applications are given.

STRUCTURE

FERROCEMENT has a structure as shown in figure 1. The reinforcement components are layers of woven or welded grids with square or hexagonale meshes. For greater thickness and for further strengthening, you may have additional reinforcement of thicker rods in one or two directions. The spaces are filled with mortar, which composition shall permit the mortar to penetrate into all voids without difficulties.

With this structure it is possible to produce relatively thin subjects, which can be formed to shells or other curved shapes. You also get a material with a tensile strength that is higher than for normal reinforced concrete. The ability to resist deformations without cracking is increased, so is the durability.

COMPOSITION

As mentioned above FERROCEMENT consists of meshes, rods and mortar.

Meshes

The reinforcement meshes have normally a width from 5 to 20 mm, and a diameter between 0.5 to 1.5 mm. Mostly, the mesh is welded,

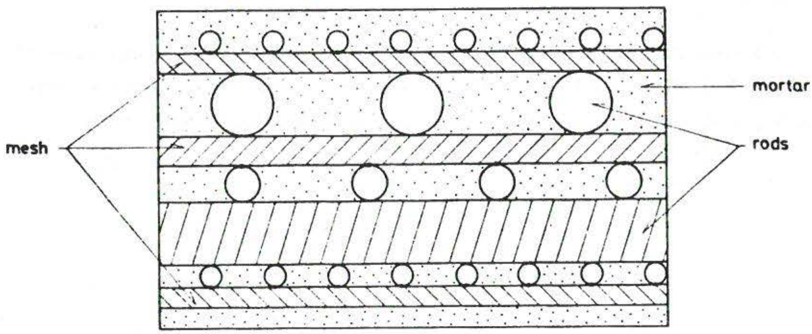


Figure 1: Structure of FERROCEMENT.

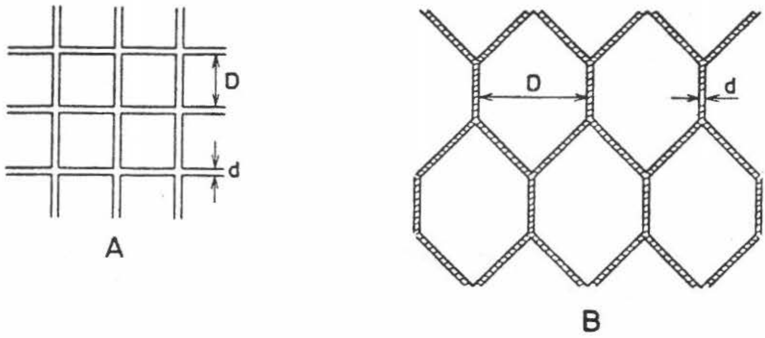


Figure 2: A, welded square mesh.
B, woven hexagonal mesh.
D, mesh width.
d, mesh diameter.

but also woven meshes are used, especially if you use hexagonal meshes (chicken meshes). Figure 2 shows the two forms of meshes.

The material is normally ductile or high-strength steel, and often the meshes are galvanized. Also reinforcement of aluminium can be used.

Rods

The rods are mostly deformed steel with a diameter of 5 to 15 mm and a distance between them from 50 to 100 mm.

Mortar

The mortar consists of cement, water, fine aggregate and sometimes admixtures.

1. The cement ought to be ordinary portland cement (OPC) or a sulphate resistant cement (SRC) for special purposes.

2. Water must be from waterworks or from source, where the suitability of the water has been tested.

3. Fine aggregate must be clean and well-graded, because of the water demand. It must not be too coarse. As a rule, the maxi-

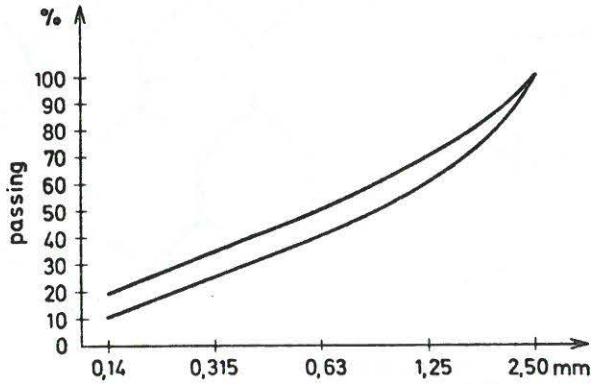


Figure 3: Limits for sieve line for aggregate (1).

mum diameter not must be greater than 1/3 of the mesh width. A maximum size is 1/8" or 3 mm. 8 to 10% of the material should be smaller than 1/20" or 1/8 mm.

Figure 3 shows the limits of the sieve line for the aggregate, but variations in the interval 0.3 to 1.2 mm can be tolerated (20).

Too many fine particles (< 0.2 mm) will give a greater water demand, and you will have weaker particles. Too many coarse particles (> 1 mm) make the mix harsh, unworkable and affect the bond, penetration and compaction.

4. As admixtures you can use puzzolans to give the mortar better workability, plasticisers are used for lowering the water demand and nitrite salts are used for corrosion inhibition. Impurities as clay, salt and expanding aggregates must be avoided.

Composition

The properties of FERROCEMENT depend on the amount of the reinforcement and the composition of the mortar.

Nervi cited, that the reinforcement normally weighs about 400-500 kg/m^3 FERROCEMENT. This demand has been further specified, and instead a demand is made to the specific surface of the reinforcement S, which is calculated as

$$S = \frac{\text{total surface of the reinforcement}}{\text{total volume of the FERROCEMENT}}$$

with the dimension length^{-1}.

The value S is an important parameter in description of mortar with reinforcement.

As an example the S-value is calculated, if if you have W kg reinforcement/m^3 FERROCEMENT, consisting of mesh with a diameter of d mm. The total length l in mm is calculated as

$$\pi \cdot d^2 \cdot l \cdot \varrho \cdot 10^{-9}/4 = W$$

and the total surface s is

$$s = l \cdot \pi \cdot d = W \cdot 4 \cdot 10^9/\varrho \cdot d$$

where ϱ = specific weight of the reinforcement in kg/m^3.

If W = 450 kg/m^3, d = 1 mm and ϱ = 7800 kg/m^3 the S-value is

$$S = 230\ \text{m}^{-1}.$$

For most purposes the value of S varies from 150 to 400 m^{-1}.

The S-value can be divided in two: S_L and S_V (longitudinal and vertical) as shown in figure 4.

S_L is the specific surface in the longitudinal or loading direction and S_V in the vertical direction. The values of S_L and S_V are not

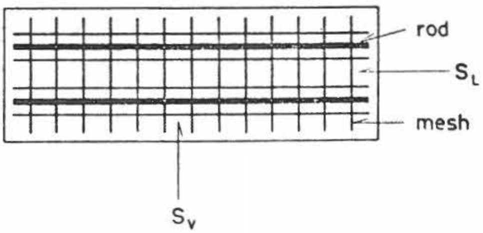


Figure 4: S_L and S_V.

equal, when you have further reinforcement with rods placed differently in slabs. But you always know that

$$S = S_L + S_V$$

The total surface of the reinforcement S_R is

$$S_R = V \cdot S = V \cdot (S_L + S_V)$$

where V is the volume of the FERROCEMENT.

In the mortar the water/cement ratio w/c should have values between 0.35 to 0.40, and the aggregate/cement ratio a/c from 1:1 to 3:1. There should be more than 600 kg cement/m^3 FERROCEMENT (5). As an example the composition of a mortar with w/c = 0.40 and a/c = 2:1 is calculated.

Composition	1 m^3 mortar	
Component	kg	litre
Cement	670	215
Water	270	270
Fine aggregate	1340	515
Total	2280	1000

If you have 450 kg reinforcement/m^3 FERROCEMENT, you may have

$$(1 - 450/7800) \text{ m}^3 \text{ mortar}$$

and the total weight of 1 m^3 FERROCEMENT is therefore

$$(1 - 450/7800) \times 2280 + 450 \text{ kg} = \underline{2600 \text{ kg/m}^3 \text{ FERROCEMENT}}$$

In this calculation the air-content of the mortar (< 1%) is ignored.

PROPERTIES

The most important properties are discussed in the following. They can be divided into the behaviour of:

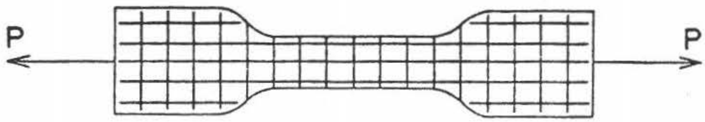


Figure 5: Tensile stress specimen.

tension
compression
bending
impact
fatigue
dynamics.

Tensile behaviour

In the following some fundamental aspects of mechanical behaviours are described, and in many cases these aspects can be applied to other mechanical tests (14).

Figure 5 shows a specimen for tensile stress measuring. If you subject it to a stress, you will see, that the tensile behaviour reflects that of the steel mesh. If the reinforcement is made of ductile steel, you get large ultimate deformations, is it made of high-strength steel, it has a smaller ultimate deformation.

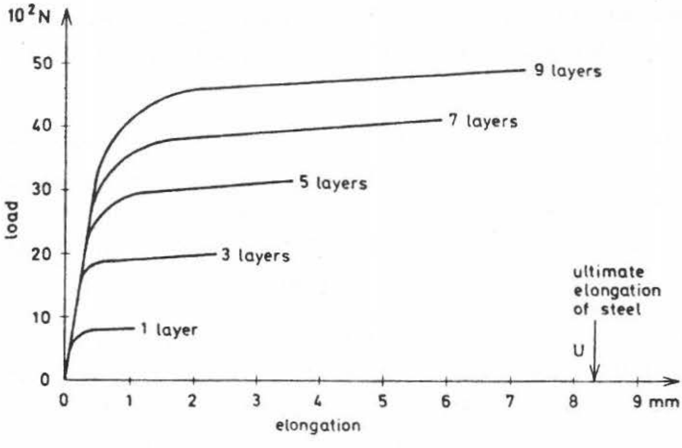


Figure 6: Load-elongation curves.

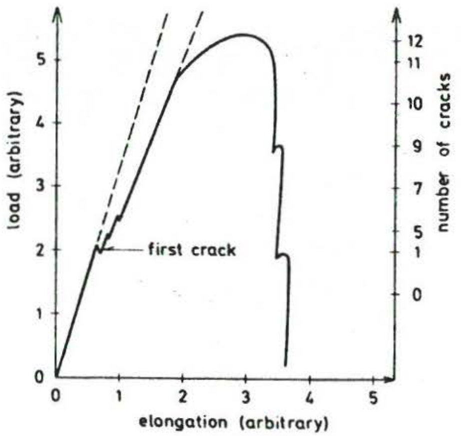


Figure 7: First crack determination.

Figure 6 shows load-elongation curves by tensile stress. You see, that if you increase the volume of steel from 1 layer to 9 layers, you also increase the maximum load, the specimen can carry. Another interesting thing is that the ultimate elongation also is increased, so that it approaches the value of the steel mesh alone (point U).

Figure 7 shows a load-elongation curve by tension. You see, that at a certain load, the slope of the curve tends to be less than before. This point is called the point of first crack, because no cracks were seen before this point. With further loading the number of cracks will increase.

At failure the number of cracks is increased by increasing the number of layers. If you use high-strength steel, the cracks are more difficult to see than with ductile steel. If you plot the ultimate load of the composite versus the load-carrying capacity of the reinforcement, you get equality as shown in figure 8.

In figure 9 the modulus of elasticity is treated. The modulus is plotted versus the volume fraction of reinforcement. You see, that the modulus depends on the crack conditions of the concrete. In the uncracked state the modulus of elasticity $E_{F,1}$ can be predicted as

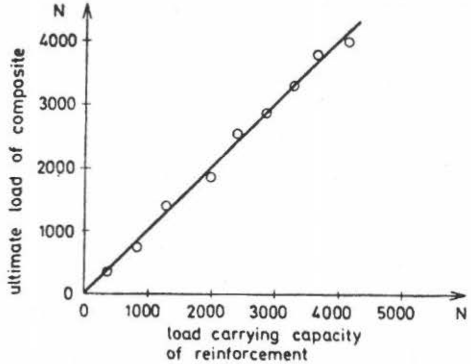


Figure 8: Ultimate load of composite versus load-carrying capacity of reinforcement.

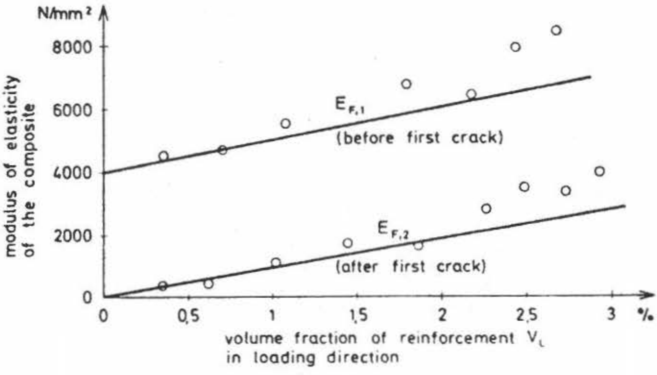
$$E_{F,1} = E_M(1 - V_L) + E_{RL}\,V_L \simeq E_M + E_{RL}\,V_L$$

In the cracked state the modulus of elasticity $E_{F,2}$ can be predicted as

$$E_{F,2} = E_{RL}\,V_L$$

where $E_{F,1}$ and $E_{F,2}$ = modulus of elasticity of FERROCEMENT in the uncracked/cracked state.

E_M = modulus of elasticity of the mortar; the value is depending on the degree of hardening, α. $E_M \simeq k\alpha^3 \simeq 2 \times 10^3\,\alpha^3\,N/mm^2$.



Figur 9: Composite modulus of elasticity in tension.

E_{RL} = modulus of elasticity in the loading direction of the reinforcement = 1 to 2 x 10^5 N/mm^2.

V_L = volume fraction of the reinforcement in the loading direction.

The analytical formulas give a lower value than the experimental facts. You can give following reasons for this:

1. The effect of transverse reinforcement is neglected.
2. The influence of the mortar is neglected.
3. The mortar should contribute somewhat even in the cracked state.
4. Welded mesh gives higher values than woven mesh. An explanation of this is, that the mortar starts spalling off and the mesh is exposed, when you use woven mesh, where the weaving angle, a, calculated as

$$a = \frac{\text{wire diameter}}{\text{wire spacing}}$$

is greater than 0.1.

If you plot the stress at the first crack versus the volume content of steel, you do not get a simple curve; but if you plot the stress at first crack versus the value of S in the loading direction (S_L) instead, you get a very simple curve, see figure 10.

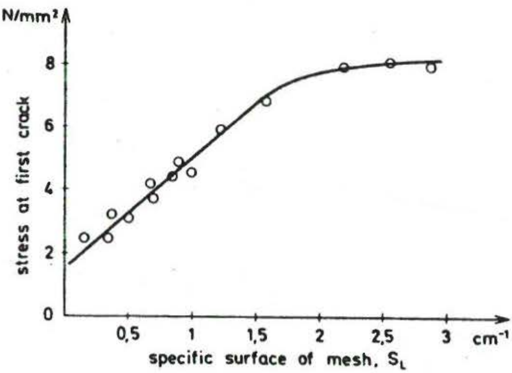


Figure 10: Stress at first crack versus S_L-value.

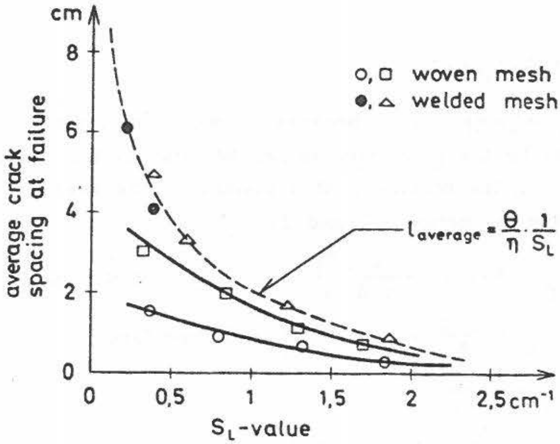


Figure 11: Experimental values of crack spacing at failure versus S_L-value and theoretical curve.

For several kinds of steel, you get nearly the same stress at first crack with the same value of S_L. But the elongation will be different. Also the spacing of cracks can be plotted against the S_L-value as shown on figure 11. This figure shows, that the larger the surface area the larger the number of cracks and this explains, why you have a large elongation at failure with larger surface area.

The results observed can be compared with the theory of crack development. If you have a specimen with reinforcement and you give it a tensile stress, a crack will arise at a distance l from the end (figure 12). If the tensile strength σ_t is reached and the shear stress is τ, the distance l is given by

$$\pi \cdot d \cdot l \cdot \tau = A \cdot \sigma_t$$

where d is the diameter of the reinforcement and A is the cross-sectional area of the specimen.

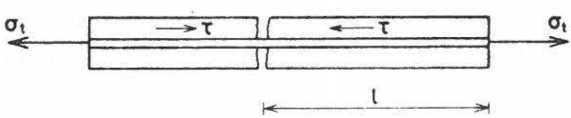


Figure 12: Tensile specimen.

You see, that

$$l = A \cdot \sigma_t / \pi \cdot d \cdot \tau$$

l must be the minimum value, because τ cannot be greater and the distance 2l must be the maximum value, because in this case a new crack may arise in the middle of this distance. The average spacing l_{avg} will therefore be between l and 2l.

$$l_{avg} = \theta \cdot l = \theta \cdot \frac{A}{\pi \cdot d} \cdot \frac{\sigma_t}{\tau} \qquad 1 < \theta < 2$$

In this formula $S_L = \frac{\pi \cdot d}{A}$ and $\eta = \frac{\tau}{\sigma_t}$ and therefore

$$l_{avg} = \frac{\theta}{\eta} \cdot \frac{1}{S_L}$$

As an example $\theta = 1,5$ and $\eta = 1,6$ you can plot l_{avg} versus S_L and get a very good correlation with the experimental results (figure 11).

The average crack-width w_{avg} can be calculated from the theory. When the stresses of the reinforcement in the cracks are similarly great, the total extension of a distance l is

$$w = \sigma_R \cdot l / E_R$$

The average width is therefore

$$w_{avg} = \theta \cdot w = \frac{\theta}{\eta \cdot S_L} \cdot \frac{\sigma_R}{E_R}$$

where σ_R and E_R are the stress and modulus of elasticity of the reinforcement. You can make a further calculation and the formula is

$$w_{avg} = \frac{\theta}{\eta \cdot S_L} \left[\frac{\sigma_R}{E_R} - \frac{\tau}{4} l_{avg} \left(\frac{4}{E_R \cdot d} + \frac{S_L}{E_M} \right) \right]$$

where E_M is the modulus of elasticity of mortar and d is the diameter of the reinforcement. You see, that the greatest value of w_{avg} is the value mentioned above.

Shah (14) has made a few experiments to measure the crack width and found that the lower the specific surface, the larger the width.

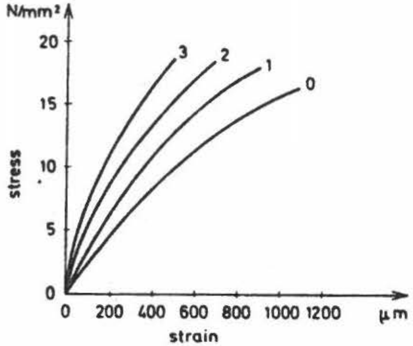


Figure 13: Stress-strain diagram at compression.
0, 1, 2, 3: % reinforcement.

Compression behaviour

FERROCEMENT under compression was also studied (13). Compressive stress and modulus of elasticity were measured on specimens with the dimensions 3 x 10 x 30 cm. Figure 13 shows graphs for stress versus strain in compression.

You see, that the behaviour under compression is similar to that of ordinary reinforced concrete. The ultimate compressive strength varies only a little with the steel content. Figure 14 shows, that the compressive strength decreases, if the steel content is too high. The

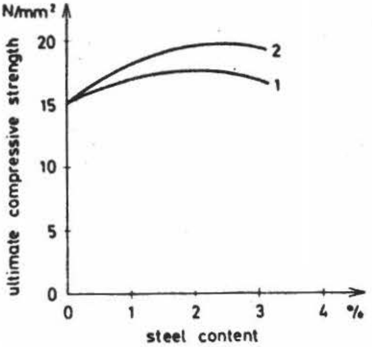


Figure 14: Compressive strength versus steel content.

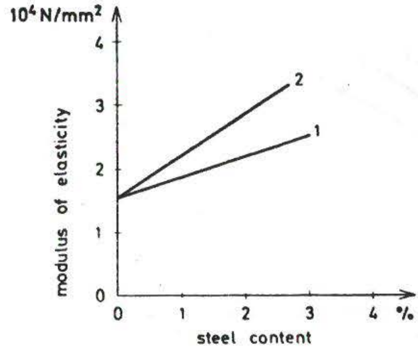


Figure 15: Modulus of elasticity versus steel content.

explanation of this is, that the specimens begin to split due to buckling of the reinforcement. Curve 2 is for reinforcement with a smaller diameter (higher S-value) than curve 1.

The modulus of elasticity in direct compression depends on the steel content as shown in figure 15,- compare with the conditions in tension. You see, that if you increase the diameter of the wire, the modulus is decreased. The explanation is as mentioned before: your contact surface area is smaller, when you increase the diameter. Curve 1 and 2 as before.

Bending behaviour

Experiments were made to measure the maximum bending moment a beam can sustain, and the results were compared with the theoretical results obtained (7).

The theory is based on the fact, that the ultimate moment of reinforced concrete beams depend on the dimensions, the compressive properties of the concrete and the amount, location and yield characteristics of the steel reinforcement.

Figure 16 shows a cross-section of a FERROCEMENT beam, which is loaded for bending. The ultimate bending moment is reached, when mortar in the compression zone fails, and the ultimate compression

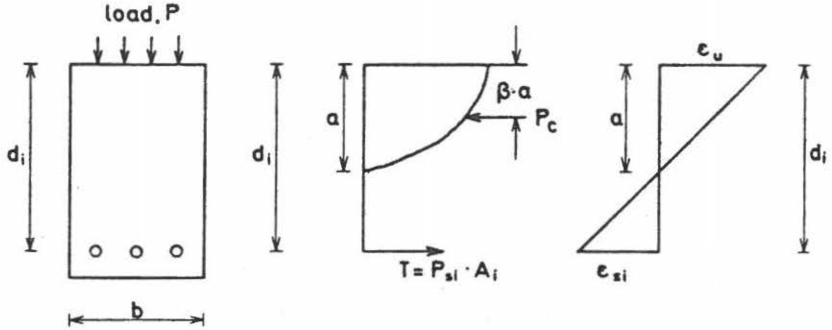


Figure 16: Stress-strain parametres in bending.

strain is $\varepsilon_{m,u} = 0,0035$ to $0,0050$. This strain was assumed to be the same as that given from a mortar with a compressive strength of σ_m. The total force P_m in the compression zone is therefore, when the neutral axis is the distance, a, from top

$$P_m = \alpha \cdot \sigma_m \cdot b \cdot a$$

and the moment M about neutral axis is

$$M = P_m \cdot (a - \beta \cdot a)$$

where $\alpha \simeq 0.70$ and $\beta \simeq 0.40$ can be derived from the stress-strain curve.

Next step is to calculate the strain of the mesh in the distance d_i. This strain ε_{si} is given from

$$\varepsilon_{si} = \frac{d_i - a}{a} \varepsilon_{m,u}$$

and the stress P_{si} is either $= E_s \cdot \varepsilon_{si}$, if this value is $< \sigma_{0,2}$, or $= \sigma_{0,2}$, if $E_s \cdot \varepsilon_{si} > \sigma_{0,2}$.

Here E_s is the modulus of elasticity of the steel and $\sigma_{0,2}$ is 0,2% strength of the mesh.

Third step is to make an equilibrium check. You calculate the two sides of this equation

$$\alpha \cdot \sigma_c \cdot b \cdot a + \Sigma P_{si} A_i \text{ (compression)} = \Sigma P_{si} \cdot A_i \text{ (tension)}$$

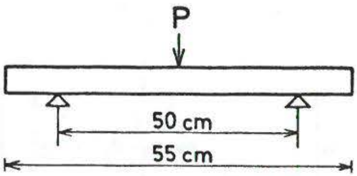


Figure 17: Slab in bending.

for a given distance, a, and you continue to calculate until you find the value of the distance, a, of the neutral axis, which gives equilibrium. For this value of, a, you calculate the ultimate bending moment M

$$M = \alpha \cdot \sigma_c \cdot b \cdot a \cdot (a - \beta \cdot a) + \Sigma P_{si} \cdot A_i\,(d_i - a)$$

Experiments show that the experimental values are greater than the calculated ones. The ratio of these values are found near 1.2 with a standard deviation of 0.1.

An investigation, the purpose of which was to see, whether there are differences in the behaviour in bending, if you change the loading direction using hexagonal meshes, is described in (20). Slabs 55 x 12 x T cm were placed as shown in figure 17. The concentrated force P and the deflection were measured until failure. 4 slabs were tested and the characteristics of the slabs are listed in table 1.

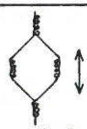
Slab	1	2	3	4
Hexagonal mesh, diameter = 0,65 mm ⟷ loading direction				
T cm	1.2	1.0	1.2	1.0
Resistance moment, cm^3	2.8	2.0	2.8	2.0
Strength, kg/cm^2	150	170	33	47
Weigth, g	1670	1630	1690	1700
Steel content, %	12.5	13.0	12.0	12.0

Table 1: Characteristics of slabs.

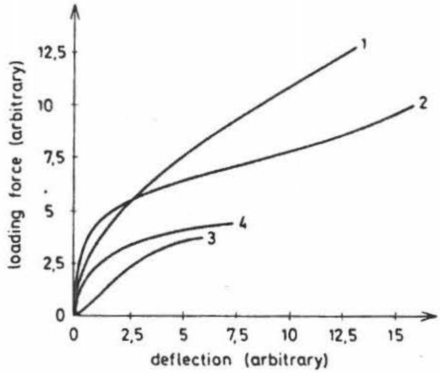


Figure 18: Loading force versus deflection.

The result of the experiment is shown on figure 18. You see that there are great differencies in the failure force P depending on the loading direction of the mesh.

Impact behaviour

Impact resistance can be measured in different ways. One method is described in the following (17). Figure 19 shows the set-up. A specimen of FERROCEMENT (F) is fixed vertically and a pendulum (P) is hanging so that, when the pendulum is released, it will hit the

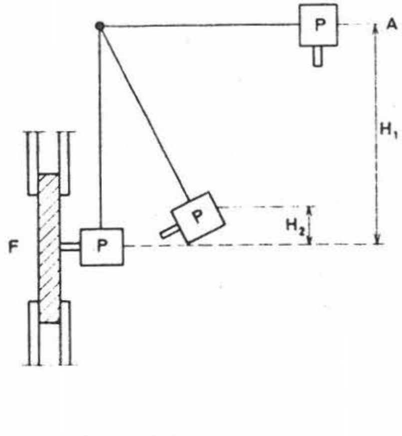


Figure 19. Impact test.

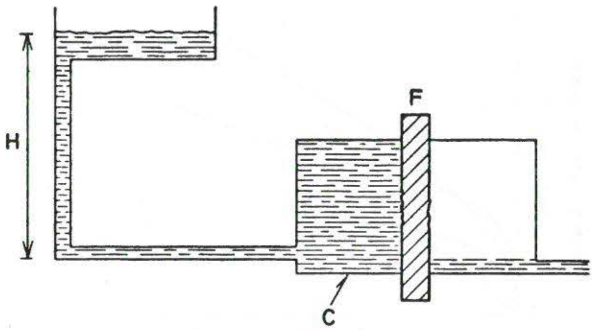


Figure 20: Leak-test apparatus.

specimen in the middle (pos. A). The absorbed energy E_{abs} can be calculated as

$$E_{abs} = W (H_1 - H_2)$$

where W is the weight of the pendulum,
H_1, H_2 are the height before and after the pendulum has hit the specimen.

After each test you can investigate the specimen for cracks, shelling etc., and you repeat the test. No easy way was found to describe the cracking behaviour related to the energy absorbed. The best way was to measure the flow of water through the specimen, when a constant value of energy was absorbed.

The arrangement for such a test is shown on figure 20. The FERROCEMENT specimen (F) is fixed water-tight in a chamber (C), where water is held at a constant pressure (H) on one side of the specimen.

If you measure the flow of water in a certain time, when a constant value of energy is absorbed, you can plot it versus the ultimate load of the reinforcement. Figure 21 shows such graphes for different values of the specific surface in the loading direction.

It is seen, that with finer meshes and stronger reinforcement, you get the lowest flow. This is important, when you use FERROCEMENT in boatbuilding, tanks and reservoirs.

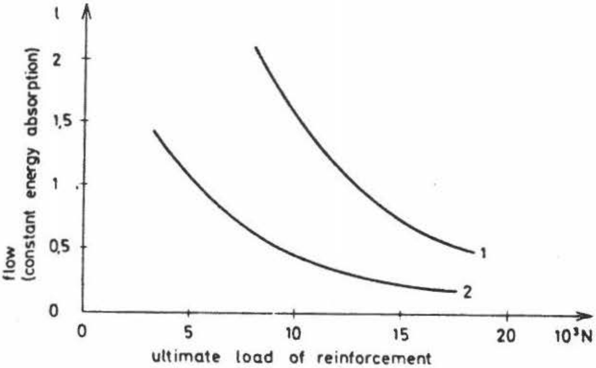


Figure 21: Flow of water versus ductility of steel and specific surface.
1. low value of S_L, 2. high value of S_L.

Fatigue behaviour

Only a few experiments have been made to measure the fatigue behaviour. One investigation is described here (11). Figure 22 shows the loading arrangement of a plate 60 x 60 cm. In the direction x you give the plate a pulsating load with a velocity of 1 cycle/second, and you measure the number of cycles until failure.

If you plot the load amplitude = difference between maximum load and minimum load in % of the ultimate static load versus the number of cycles, you get a decreasing curve, and you can determine the value of the load amplitude, which can resists e.g. 10^6 cycles, see figure 23.

The modulus of elasticity can be calculated from the first load cycle. Values about 10^4 N/mm^2 is found with a standard deviation about

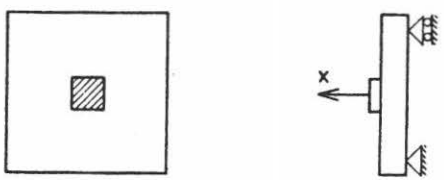


Figure 22: Fatigue test arrangement.

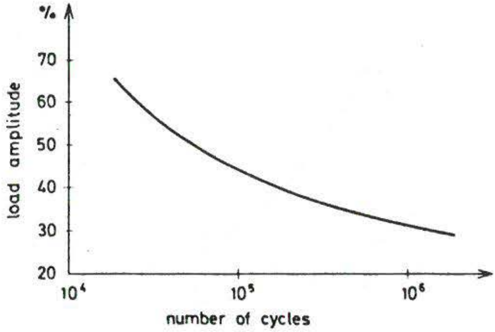


Figure 23: Fatigue strength.

5×10^2 N/mm^2. The deflection of the plate will increase, when the number of cycles is increased.

Dynamic behaviour

An experiment is mentioned in (10), where a comparison is made between panels of FERROCEMENT, GLASS FIBRE REINFORCED POLYESTER (GFRP) and PLYWOOD subjected to dynamic point loads.

The conclusion was, that at the same unit weight GFRP-panels were much stronger than the other two, and at the same unit price PLYWOOD panels were the weakest. Depending on the content and the kind of glass fibre, GFRP-panels were sometimes stronger than FERROCEMENT panels.

A shiphull made of GFRP with a thickness of 8 mm and a weight of 11.6 kg/m^2 and a shiphull made of FERROCEMENT with a thickness of 25 mm and a weight of 64 kg/m^2 seem to have the same dynamic strength due to point load.

DURABILITY

Permeability

FERROCEMENT is a very dense material with a low permeability. Generally, a low water/cement ratio and a high cement content will lower the permeability. FERROCEMENT specimens can sustain a water pressure, which is 5 to 10 times the water pressure a non-reinforced mortar can sustain (2). The water absorption should also be as low as possible, if you use FERROCEMENT under steady or periodical water pressure. You cannot prevent, that there will be 5 to 10% water in the mortar ((5):< 5%), and it is sometimes necessary to give steel a protection against corrosion.

Freezing/thawing

Generally, FERROCEMENT has a very good resistance against freezing and thawing. Experiments show, that after more than 150 cycles (5 hours a $-17^{O}C$ and 6 hours at $+15^{O}C$), you could not see cracks and other destructions of the specimens. The weight-loss was less than 1% by weight. The permeability was in practice unchanged (2).

Corrosion

Your reinforcement in FERROCEMENT should be well protected against corrosion. The necessity of this protection is still an open question. Many boats and containers are made without protection and are in good condition even after long-time use. You must have a greater thickness of the layer of mortar, if you use FERROCEMENT with a low S-value. The layer may be greater than 5 mm down to 2 mm for high S-values. In interior structures you can permit a crack width of up to 0.1 mm, but only 0.05 mm in exterior constructions (2).

WORKMANSHIP

In the literature different methods of placing and compacting the mortar are described. (2) and (21) give several examples. It is interesting to see, that the way you can produce FERROCEMENT vary from a simple in-situ casting method (plastering) to highly mechanized processes as vibro-bending or vibro-pressing. Vibro-bending is a method, where the shape is formed after vibration of the mortar down the mesh. Vibro-pressing is a method, where the mortar is vibrated and pressed down in the mesh, which is fixed

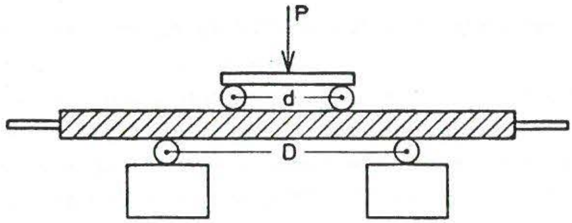


Figure 24: Loading arrangement for bending test.

below the mortar supplier. The method is much used and it is the easiest way of controlling the product.

Compacting

In the literature no comparison of test results is made from investigations, where you have different placing and compacting methods. To illustrate this some experiments have been made in the laboratory. Three slabs (30 x 70 x 4 cm) were made with a 4 layer chicken-mesh and 2 rods in the loading direction. The loading arrangement is shown in figure 24. D = 45 cm, d = 20 cm.

All 3 slabs were made of a mixture of Thames Valley sand, down 1/8" with a water/cement ratio = 0.37 and an aggregate/cement ratio = 2:1. The slabs were compacted as follows:

Slab A: Fully compacted by vibration on table.
Slab B: Applied in usual plastering ways.
Slab C: Applied by hand.

Also cubes were compacted in the ways mentioned. All the concrete were cured wet at 55°C for 3 days. The slabs were tested by measuring the load and the deflection, and figure 25 shows the obtained curves and the cube strengths.

The conclusion is, that with better compaction, you get higher deflection values and higher failure strength. The same applies to cube B and C, but there are great differencies in the two slabs. Compacting is an important parameter, when you wish to obtain good results with FERROCEMENT as for concrete as well.

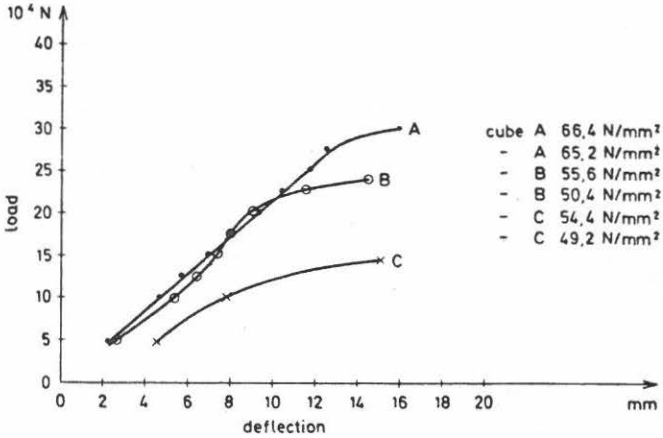


Figure 25: Load-deflection curves by bending.

Curing

Generally, mortar or concrete must be cured well to get highest possible strength. FERROCEMENT is often used in relative thin subjects and there is a danger of drying out the mortar. Normally the specimen must be kept wet in at least 7 days for OPC at ambient summer temperatures. If the curing is not sufficient, you get shrinkage cracks in the mortar with possibilities of exposing the reinforcement to air (6).

Cost

As an example table 2 gives the specifications and prices for two boats (20).

Working time

The approximate working hours for building and casting of hulls are shown below (20).

Length, m	Working time, h
8	200
10	650
12	1000
14	1500
16	1800

	9 m yacht	10 m fishing boat
Mesh	6 layers, 12 mm □ welded mesh, 0.9 mm dia.	
Rods, along-ships	6 mm O. 50 mm distance	
Rods, across-ships	none	4mmO. 100mm distance
Thickness, mm	17	20
Weight, kg/m^2	56	66
Cost, Dkr/m^2	55	62
Cost, Dkr/kg	1	1
Prices in 1974 value. £ 1 = 13 Dkr.		

Table 2. Comparison of 2 boats.

FIELDS of APPLICATIONS

FERROCEMENT has many different fields of applications. One of its first uses was for boats, which is described in the literature (1, 2, 4). A FERROCEMENT hull has many advantages compared to a hull made from steel, wood or fibre glass. For boats with a length from 10 to 40 m

1. the construction-cost is 2/3 of the cost for wood,
2. the impact resistance is the best for FERROCEMENT, because of the abscence of notch and fragile fracture, and you have no water penetration,
3. the repair is easy,
4. the weight is nearly the same as for fibre glass, and not so high as steel or wood for bigger hulls,
5. the fire resistance of REINFORCEMENT is good,
6. the maintenance is at a minimum, and FERROCEMENT is rot and borer resistant,
7. the inside spaces are greater, because of the abscence of frames in FERROCEMENT,
8. the vibration is smaller and the noise from the water is less,
9. the coefficient of heat conduction of FERROCEMENT is 1/6

of the value of steel, which means that inside the boat it is warm in winter and cold in summer,

10. the hull is going to be stronger with time, because of the hardening of the cement.

FERROCEMENT used for boats and other watertight subjects as tanks, siloes and pipelines shall have a composition with a relatively high S-value, e.g. S higher than 250 m^{-1}. For building constructions: roof-, wall- and floor elements the S-value can be lower. Instructions for calculations of FERROCEMENT constructions are given in (2).

FERROCEMENT is used for food-storage and food-processing equipment and low-cost roofing (3), and FERROCEMENT has some applications in lining of mining shafts and tunnels (21). An interesting application is the use of FERROCEMENT for vessels and lines for transporting liquid natural gases. The temperature of these gases (- 160°C) gives problems in selecting materials for containers, etc. Ordinary steel becomes brittle and alloy steel is too expensive. The properties of FERROCEMENT has been studied. In tension the fracture strength is increased (15%) and the ultimate elongation is decreased (24%) at low temperature (- 195°C) in comparison with room temperature (14).

CONCLUSION

FERROCEMENT is a building material, which consists of mortar with a reinforcement of meshes and rods. It can be compacted and formed in thin shapes for use in boats, roofs, shells and other curve-shaped subjects.

The material is described in this report. The structure and the composition of the material is treated. Of the properties the tensile behaviour is treated in detail and many of the characteristic phenomena, which you have here might in many cases apply to the other mechanical properties: strength-relationships to wire diameter and wire amount, crack width and crack spacing. FERROCEMENT in compression, bending, impact and dynamics are also treated. The durability conditions are mentioned. Finally problems in practice are treated, and fields of applications are briefly referred.

The purpose os this report - a literature study of FERROCEMENT - is now completed. The interesting field pertaining to the design possibilities is not studied here. The report gives a background for further study of the material, especially for use in the building sector.

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